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Editorial

Current Trends and Challenges in Location-Based Services

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Abstract: Location-based services (LBS) are a growing area of research. This editorial paper introduces the key research areas within the scientific field of LBS, which consist of positioning, modelling, communication, applications, evaluation, analysis of LBS data, and privacy and ethical issues. After that, 18 original papers are presented, which provide a general picture of recent research activities on LBS, especially related to the research areas of positioning, modelling, applications, and LBS data analysis. This Special Issue together with other recent events and publications concerning LBS show that the scientific field of LBS is rapidly evolving, and that LBS applications have become smarter and more ubiquitous in many aspects of our daily life.

Keywords: location based services; LBS; context-aware services; positioning; mobile interfaces; privacy; tracking; global positioning system (GPS)

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1. Introduction

Location-based services (LBS) are computer applications (specifically, mobile computing applications) that provide information depending on the location of the device and the user, mostly through mobile portable devices (e.g., smartphones) and mobile networks [1,2]. Recent years witnessed rapid advances in LBS with the continuous evolution of mobile devices and telecommunication technologies. LBS became more and more popular not only in citywide outdoor environments, but also in shopping malls, museums, airports, big transport hubs, and many other indoor environments. They were applied in emergency services, tourism services, navigation guidance, intelligent transport services, entertainment (gaming), assistive services, healthcare/fitness, social networking, etc. [3,4].

The consistent prevalence of LBS-related research motivated this Special Issue, which called for original research contributions on all aspects of LBS, covering outdoor and indoor positioning, context modeling, user interfaces and interaction, innovative LBS applications, social aspects of LBS, and analysis of LBS data. After the review process, 18 papers were accepted and published, which addressed a broad range of related topics. This editorial aims to capture the main trends in current LBS research, by summarizing the contents of the Special Issue, as well as recent events and publications concerning LBS. After analyzing the state of the art of LBS, we briefly discuss some potential issues that need further research efforts. The initiative for the development of a research agenda by the Commission on LBS of the International Cartographic Association (ICA) is also introduced to motivate further research, and to stimulate collective efforts to bring LBS research to a higher level.

2. The Scientific Field of LBS

To further discuss research issues in LBS and to introduce the contents of this Special Issue, it is pertinent to first examine the key research areas within the scientific field of LBS.

Unlike other traditional geographic information systems (GIS) and web mapping applications, LBS are aware of the context their users are currently in, and can adapt the contents and their presentation accordingly [5]. Another distinct characteristic is that LBS are often used in a dynamic and mobile environment [2]. These distinct characteristics make the development of LBS applications unlike other GIS applications, and open many research questions beyond the scientific field of geographic information science (GIScience).

In general, research pursued in the scientific field of LBS can be classified into seven broad areas: positioning, modeling, communication, evaluation, applications, analysis of LBS-generated data, and social and behavioral implications. The first three areas represent the core of LBS ("how to make it work"), as every LBS application needs to deal with the main tasks of positioning, data modeling, and information communication.

- **Positioning**: As the name suggests, LBS need to determine the location of the user. Therefore, positioning or location determination is a crucial part of LBS. In many outdoor environments, global navigation satellite systems (GNSS) such as global positioning systems (GPS) have made this a trivial task. However, in many other areas, such as dense urban environments, indoors, and underground, providing accurate and reliable positioning is still a considerable technical challenge, despite the recent advances in indoor positioning. Research on this aspect mainly focuses on ubiquitous positioning, with the aim of providing an accurate and timely estimate of a user's or an object's location anytime and anywhere.
- **Modeling**: Users are central to LBS. For supporting users, LBS should model location, context, characteristics, and needs of a mobile user, and provide services adapted to them. Meanwhile, geographic space, and places relevant to the LBS applications should also be modeled effectively. Research on this aspect mainly focuses on how these kinds of information can be modeled for LBS, and how they can be used to provide personalized and context-aware services.
- **Communication**: From a user's perspective, LBS applications provide relevant information via mobile devices to support his or her decision-making and activities in space. This can be considered as a communication process, in which relevant (spatial–temporal) information is conveyed from LBS applications to the users. Research on this aspect mainly focuses on two essential research questions: What information should be communicated to the user, and in which presentation forms (e.g., mobile maps, augmented reality, and verbal)?
- **Applications**: Rapid advances in the above aspects (i.e., positioning, modeling, and communication) triggered the development of many innovative LBS, opening applications in various domains such as navigation and wayfinding, tourism, social networks, entertainment, healthcare, and transportation.
- **Evaluation**: To ensure that a developed LBS application meets a user's needs, evaluation of such services, regarding usability and usefulness, is essential. Due to the fact that LBS are often used while people are on the move, dynamic aspects of mobile decision-making must be considered. This poses many methodological challenges.
- **Analysis of LBS-generated data**: LBS applications not only help facilitate people's daily activities and decision-making in space, but also generate a lot of data about how people use, travel, and interact with each other in the environment. Therefore, a branch of research within the scientific field of LBS focuses on analysis of these data, especially location-based tracking data, social media data, and crowdsourced geographic information, so as to better understand people's behavior in different environments. Mining these (large) spatial data potentially enables various innovative applications in domains like transport, urban planning, smart cities, and social sciences, as well as provides insight to further improve the LBS applications that generate these data.
- **Social and behavioral implications**: Privacy issues are a long-standing challenge for LBS. In recent years, the increasing use of LBS, as well as the growing ubiquity of location/activity-sensing technologies, has brought further privacy challenges, as well as some other social, legal, and ethical issues. Several key questions are often addressed in this context, for example, "What are

the privacy and ethical issues of LBS?", and "How can we best address users' privacy and ethical concerns in LBS?".

3. Current Trends as Reflected in This Special Issue

The 18 accepted papers in this Special Issue were thematically classified according to the above research areas. In general, they covered topics related to the research areas of positioning, modeling, applications, and analysis of LBS-generated data. In the following sections, we briefly summarize these papers to reflect the current trends in these areas.

3.1. Positioning

Positioning or location estimation is a key task in LBS. As briefly mentioned before, current research on this aspect mainly focuses on the development of methods to provide accurate and reliable location estimation in indoor environments, and other adverse GNSS environments. In this Special Issue, this topic was addressed in five papers, which were further divided into two groups: positioning based on a single sensor technology (e.g., WiFi fingerprinting or Bluetooth fingerprinting), and sensor fusion.

For the first group, studies focused on how a particular sensor technology (such as WiFi, Bluetooth, or radio-frequency identification, RFID) could be used for positioning. As an example, WiFi fingerprinting attracted significant research interest in the past few years. Song et al. [6], for instance, focused on this aspect, and proposed a WiFi fingerprinting method based on hidden naïve Bayes to provide indoor positioning. To improve location accuracy and computational consumption, a method based on ReliefF and the correlation coefficient was proposed to select the best discriminating access points (APs) in WiFi fingerprinting.

The second group of papers made use of various sensor technologies, and developed sensor fusion methods to provide better location estimation. Li, Wang, and Yuan [7] developed a heading estimation method with real-time compensation, based on a Kalman filter, using the low cost Micro-Electro-Mechanical System (MEMS) Inertial Measurement Unit (IMU). It fused a magnetic meter, an accelerometer, and a gyroscope. The experiment showed that meter-level positioning accuracy could be achieved only using a low-cost MEMS IMU. Lai et al. [8] developed a method for step-length estimation (SLE) in pedestrian dead-reckoning systems, based on multi-sensor (accelerometer and gyroscope) fusion, and fuzzy logic. The wide-range SLE developed in their study was achieved using a knowledge-based method to model the walking patterns of the user. The authors showed that the proposed method was suitable for indoor and outdoor environments, and did not depend on the availability of map information, or any pre-installed infrastructure. Li, Liu, et al. [9] presented an improved WiFi/pedestrian dead-reckoning (PDR) integrated positioning system, which used an adaptive and robust filter. The adaptive filter was based on scenario and motion state recognition, while the robust filter was based on the Mahalanobis distance. They were combined and used in the system to reduce the effect of gross errors on the dynamic and observation models. Li, Wang, et al. [10] proposed a method of fusing WiFi and PDR for indoor positioning. It could adaptively determine the dynamic noise of a filtering system according to pedestrian movement (straight or turning), and thus, restrained the jumping or accumulation phenomena of WiFi positioning, and the PDR error-accumulation problem. The experiment showed that the positioning error could be reduced from 4.09 m to 2.32 m, when integrating PDR with WiFi fingerprinting.

3.2. Modeling

Research on modeling in LBS aims to effectively represent location, context, characteristics and needs of a mobile user, as well as the geographic space, and places relevant to the applications. To this end, five papers covering this topic were included in this Special Issue, addressing aspects related to data storage, and spatial querying.

Wang et al. [11] proposed a physical storage model for accessing and updating navigation data. It used a reach-based hierarchy method of building a road hierarchal network, and adopted a linear link-coding method for multi-level links. An experiment with a navigation map of East China and real-time traffic information showed that the proposed model was efficient in vehicle navigation applications.

In the next four papers, the focus shifted from data storage to querying in spatial databases. Attique et al. [12] proposed an algorithm for top-k spatial preference queries in directed road networks. To reduce query processing time, a method for the pruning and grouping of feature objects was proposed. Their experiment showed that the proposed algorithm significantly reduced the query processing time when compared with the period solution. Zhang, Lu, and Chen [13] addressed the problem of continuous range queries of moving objects in networks. They presented a line-graph-based algorithm, which was characterized by a novel graph-based expansion tree structure to monitor queries in an incremental way. To improve performance, the authors created a series of data structures, such as bridgeable edges and distance edges. Zhang, Lu, and Xu [14] combined moving object databases, and social network systems, and proposed a data model to integrate trajectories, their underlying geographical space, and their social relationships for constantly moving objects. A set of user-defined data types, and corresponding operators were proposed to facilitate geo-social queries of moving objects. Unlike the above papers, the paper by Albanna et al. [15] aimed to provide personalized location recommendations considering users' interests. Locations (e.g., venues) that matched an individual user's interest and that were within a predetermined geo-range were queried and ranked. The authors also addressed the code-start problem, which refers to the common issue of recommender systems failing to provide satisfying recommendations to new users.

3.3. Applications

With rapid advances in the enabling technologies (i.e., positioning, modeling, and communication), recent years saw many innovative LBS applications, ranging from traditional LBS applications in fields like mobile guide and navigation, to those in more recent emerging fields such as social networking, entertainment, healthcare/fitness, intelligent transportation systems, assistive systems, disaster and emergency, and education. In this Special Issue, three papers particularly focused on navigation and wayfinding, aiming to enhance navigation systems with landmarks.

Rousell and Zipf [16] presented a prototype navigation service that extracted landmarks suitable for navigation instructions from the OpenStreetMap dataset, based on six primary attributes: visual/semantic saliency, distance from waypoint, visibility, position, location, and uniqueness. Landmark-based route instructions were then generated to aid pedestrian navigation. Similarly, Weng et al. [17] proposed a method of rapidly extracting urban landmarks from basic spatial databases on large spatial scales, based on the dual aspects of spatial knowledge acquisition, and public spatial cognition rules. Specifically, the salience was computed by considering two weighted parameters: the total number of check-ins, and local accessibility. Liao and Dong [18] designed a three-dimensional (3D) map that combined salient 3D landmarks, and two-dimensional (2D) layouts to support pedestrian navigation, and evaluated gender differences in using the 3D map. For the evaluation, eye tracking was applied. The authors showed that males using the 3D map paid more attention to landmarks in the environment, and performed better than when using the conventional 2D map, while female performance did not show any significant difference when using the two types of map. These empirical results provided some insight for the design of map-based pedestrian navigation systems.

3.4. Analysis of LBS-Generated Data

The increasing use of LBS, as well as the growing ubiquity of location/activity-sensing technologies, has led to the accumulation of a large amount of location-based social media data, and tracking data. These data often reflect how people use, travel, and interact with each other in the environment. In recent years, analysis of these data attracted significant interest from researchers in various disciplines. Typically, these data are used for human-mobility modeling, urban-semantics modeling, and social-network analysis. Five papers in this Special Issue focused on the analysis of LBS-generated data. We divided them into two groups: one dealt with location-based social media data, and the other with location-based tracking data.

The first group focused on location-based social media data, and consisted of four papers. Considering that fewer than 2% of tweets are geotagged, Laylavi et al. [19] developed a multi-elemental location-inference method that tried to predict the location of tweets by exploiting their textual contents, as well as the user's profile location, and place labeling. They showed that the proposed method significantly outperformed existing ones, and was able to infer the location of 87% of the tweets, with an average distance error of 12.2 km, and a median distance error of 4.5 km. Lee et al. [20] focused on clustering location-based social media data with the aim of showing them on multi-scale map services. They proposed a method of determining the appropriate sizes of clusters for various zoom levels, considering both quantitative and qualitative aspects, while minimizing the modifiable-areal-unit-problem (MAUP) effect. Töpfer's radical law was used to determine the proper number of clusters for various zoom levels. Abbasi et al. [21] used location-based check-in data (Foursquare) to predict collective human mobility, that is, flow from an origin toward a destination. Specifically, the authors applied a rank-based model, and considered three scenarios including rank distance, the number of venues between origin and destination, and a check-in-weighted venue scheme to compute the ranks. Unlike Abbasi et al. [21], who aimed to model human mobility, Ji et al. [22] focused on urban semantics. The authors proposed a clustering method to detect themed streets of a specific region, using location-based check-in data. They used street segments as a basic unit for analysis. The authors evaluated the proposed method with a market field-survey report to illustrate its performance.

Unlike the above studies using location-based social media data, Qiu and Wang [23] focused on location-based tracking data (i.e., GPS traces). They proposed a framework for segmentation and grouping, for road-map inference from GPS traces. The key to this framework was the partitioning of all points of GPS traces into clusters that represented nearly straight curves to recover the road map. Experimental results showed that their method was robust to noise and the variable sampling rates of GPS traces, and performed well in terms of geometric accuracy.

4. The Ongoing Evolution and Future of LBS Research

LBS are becoming more and more ubiquitous in many aspects of daily life, and attract significant research interest from various scientific disciplines. With the continuous evolution of communication technologies and mobile devices that underpin and support the services, rapid advances in LBS were observed in the past few years. In general, by summarizing the contents of this Special Issue, the recent events and publications concerning LBS, as well as recent industrial developments, several key ongoing evolutions of LBS research could be highlighted. Of particular interest were those concerning the increasing demands of expanding LBS from outdoor to indoor and mixed outdoor/indoor environments, from location-aware to context-aware, from navigation systems and mobile guides to more diverse applications (e.g., social networking, entertainment, fitting monitoring, education, and advertisement), from maps and audio only to more "natural" interfaces, and from technology-oriented to interdisciplinary research [2].

Despite the rapid advances in LBS research, many scientific challenges still exist, covering various aspects of the scientific field such as positioning, modeling, communication, applications, evaluation, analysis of LBS data, and privacy and ethical issues of LBS. For example, providing reliable, ubiquitous positioning that works anytime and anywhere remains challenging. Modeling users and their contexts to provide personalized and contextual services still needs extensive research efforts. The issue regarding the accommodation of LBS users' privacy concerns continues to be a primary challenge for LBS. Meanwhile, as LBS enter into many aspects of our daily life, this also brings forth new issues concerning the social, ethical, legal, and behavioral implications of LBS.

To motivate further LBS research and to stimulate collective efforts, the Commission on Location-Based Services within the International Cartographic Association is currently developing a cross-cutting research agenda, with the aim of identifying key research questions and challenges essential for the further development of LBS (https://lbs.icaci.org/research-agenda/). Many cross-disciplinary efforts are anticipated in the future, particularly on the interaction of geospatial science, information and communication technology (ICT), and social sciences. We expect that these efforts will improve LBS intelligence, and make them more ubiquitous in our daily life, further contributing to "positively" shaping the future of the mobile information society, into which our society is evolving.

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